Design, construction and evaluation of semi-automatic vegetable transplanter with conical distributor cup

Seyed Mohamad Javidan¹ · Davood Mohammadzamani²

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Abstract

In this research, in order to increase the speed and precision of cultivation, the semi-automatic tomato transplanter with conical distributor cup was designed and constructed. In this machine, transplants are transmitted by a semi-automatic distributor and through the conical bowls into the fall tube and transferred to the furrow formed by the furrower. In the field evaluation of the machine, these parameters were considered: the distance between the cultivated seedling, cultivation depth and angle, and the amount of physical damage to seedlings. The tests were carried out using a factorial experiment based on a completely randomized block design with ten replications. The treatments consisted of three levels of forward speed, including speed of 1, 2 and 3 km h⁻¹ and two levels of cultivation depth at 5 and 10 cm. The results showed that interaction between the forward speed and the cultivation depth had no significant effect on the variables studied, the factor of forward speed had significant effects only on the variables of deployment angle and physical damage to the seedlings, and the factor of cultivation depth was only effective on the variable of the seedling deployment angle. The most appropriate forward speed and cultivation depth were 2 km h⁻¹ and 5 cm, respectively. With a forward speed of 2 km h⁻¹ and in one cultivation row, a theoretical capacity of 0.008 hah⁻¹ was determined for the machine.

Keywords Semi-automatic transplanter · Designing and constructing · Test · Evaluation

1 Introduction

A large number of plants, especially a group of vegetables, are cultivated as transplants. Due to a prolonged growth period, unfavorable conditions for seed germination, two cultivations in one crop year in fertile soils, fine and sensitive seeds of some Vegetables and etc., this method of cultivation is superior to the other ones [7]. Today, a lot of equipment has been designed and constructed in order to mechanize vegetables transplanting, increase the speed and precision of cultivation and reduce the costs. In Iran, although large areas are under the cultivation of vegetable transplants; there has not been an extensive and coherent work in this field, and the imported equipment has been used finitely. By increasing the cultivation

of crops which can be grown as transplants, this need is more pronounced; as a result, equipment and devices for the mechanization of this kind of cultivation should be designed and constructed [9]. Mechanization of transplanting reduces the need for labor force in the cultivation process, which results in minimal damage to the seedlings and increased crop efficiency. It should be noted that this need arises when the income derived from traditional cultivation is less than the income derived from mechanized cultivation.

Tomato plant is a kind of vegetable that is cultivated as transplant. In Iran, large areas are under the cultivation of tomato transplant, and there is a need for mechanical cultivation. Mechanized tomato transplanting is performed by semi-automatic and fully-automatic methods. In the

✉ Seyed Mohamad Javidan, mh.javidan@gorganiau.ac.ir; Davood Mohammadzamani, zamani@tiau.ac.ir | ¹Young Researchers and Elite Club, Gorgan Branch, Islamic Azad University, Gorgan, Iran. ²Department of Agricultural Machinery, Islamic Azad University, Takestan Branch, Takestan, Iran.

semi-automatic method, the task of feeding the transplants into the distributor is carried out by the worker. But in the fully-automatic method, the task of feeding is carried out by the machine.

In a research, a semi-automatic machine for transplanting lettuce was designed. The speed of transplanting was 2000 seedlings per hour in the farm and the amount of error in planting at 30 cm distances, was 3% [3]. In the UAE, a transplanter was designed, in which the seedling transferring mechanism was a conveyor system and was set for transplanting seeds into pots. This single-row transplanter was towed by 45-kW power tractor and the speed of transplanting ranged from 2 to 7 transplants per min per row and was a function of the machine power system and tractor speed [1]. In Nigeria, a single row transplanter was designed, which operated with the average forward speed of 4.39 mph, field capacity of 0.39 ha and field efficiency of 60%. The transplanter required 4 workers to operate [6]. A semi-automatic transplanter was designed in which transplants were placed at certain distances in a horizontal conveyor and transferred to distributor cups, and then the cups cultivated the transplants to the ground. The machine worked at a speed of 90 seedlings per minute [8]. In order to transplant onion seedlings, a semi-automatic transplanter was designed and developed, capable of planting 108 seedlings in two rows of cultivation. For tomato seedlings, the task was done with a spacing of 45×45 cm and a speed of 0.9 km h^{-1} . The field capacity of this transplanter was 0.026 hah^{-1} . This method, compared to manual cultivation, saved 68% in labor costs and 80% cultivation time [5]. In another research, a transplanter was constructed for cultivating cabbage seedlings. The pick-up arms were V-shaped and their rotational power was provided from the ground and through the pressure wheels. The machine operated at an optimum speed of 1 km h^{-1} , and had a cultivation speed of 33 plants per row per minute. Transplanting with this machine in terms of accuracy, speed and cost, compared to the manual method, had a significant difference of 1%; therefore, the mechanized method was preferred [7]. In a study, a manual transplanter for planting vegetables was constructed which had a field capacity and a practical capacity of 0.24 and 0.2 hectares per hour, respectively. And compared to manual cultivation, had a lower percentage of physical damage to seedlings [10]. In a study, a transplant machine was constructed for onion seedlings, which was connected to a tractor through a three-point connection. The field capacity of this machine, with the speed of 0.27 km h^{-1} and 90% efficiency of 8 h of daily work, was 3000 m^2 [11]. In order to cultivate sugar beet seedling, a semi-automatic transplanter machine was designed. This machine was able to cultivate seedling in 65 cm distances and 13 cm depth. The standard deviation in comparison to the desired position was 4.5% along the

cultivation row line and 3.6% perpendicular to the cultivation row [4]. In order to automate the entire process of transplanting vegetable seedlings, a device was designed that was able to lift the transplant from the tray by a pick-up arm mechanism, and direct it to the fall tube [9].

According to the above, the importance of developing methods to reduce the cost of tomato production, especially in the planting sector, can be understood. Developing these methods, in addition to reducing production costs, will increase the interest of farmers in cultivating this product. Development and application of tomato transplanters is one of these strategies.

In this research, the design, construction and evaluation of a semi-automatic tomato transplanter with conical distributor cup is based on the indigenous technology and it is adapted to the agronomic and economic conditions of the agricultural community of Iran.

1.1 Overall objectives

1. The feasibility of semi-automatic transplanting of vegetable seedlings.
2. Creating a suitable substrate for development of mechanized tomato cultivation by the designed transplanter.
3. Transferring technical knowledge for design and construction of semi-automatic transplanters to the agricultural mechanization division.

1.2 Special purposes

1. To increase the speed and precision of mechanized transplanting.
2. To adjust the depth and spacing of cultivation rows.
3. To reduce physical damage to transplants in cultivating operations.
4. To increase farm capacity of transplanting.

2 Materials and methods

The designed machine is able to transplant in a single row. Transplanter distributors were designed in conical shape and their rotational power was provided from the ground and through a land wheel.

Beneath the cones and for them in time opening and closing, an almond-shaped piece is placed. When the cone is above the fall tube, the cam is pressed against the outer part of it and make it open, so it is possible for the seedling to fall into the fall tube. Figure 1 shows the designed distributor cup, the cam and their placements. In order to close the distributor after it passes the fall tube, a spring is placed on each side of the cone.

Fig. 1 Designed conical distributor (right) and the cam and spring placement (left)

Fig. 2 The furrower (1) Horizontal axial bearing (2) Fall tube (3) Kicker arm (4) Kicker arm shaft (5) furrower

The cone is made of the galvanized sheet and their height and diameter are 10 cm. Transplanter transfer mechanism consists of the transplant plate, the axle of transplants, bearings and cones. The fall pipe is located below the cones and is a means for directing the transplants into the furrow made by the furrower. When the transplant enters the fall pipe, it reaches the end of the tube due to its weight, and then inserted into the furrow in the soil. The main task of the furrower is to create a furrow in the soil in a way that the seedlings would be in close contact with the soil.

In this case, the width of the furrow is 10 cm and its depth is about 10–15 cm. Figure 2 shows an overview of the components of the designed furrower.

The power take-off mechanism comprises of land wheel, wheel bearing, gear chain, chain, conical gears for changing axis direction and also transferring the power to the seedling distributor and kicker arm.

Land wheel perimeter, the number of teeth of gear chain on the wheel axis, and on the horizontal axis of the distributors are crucial parts of the design, as the

distance between seedlings can be changed as a result of alteration in their measures and sizes. This proportion of the transplanter parts are calculated by formula (1) and (2) [2].

$$DC = \frac{Z_2}{Z_1} \times \frac{LP}{NUC} \quad (1)$$

where, DC is the distance between the seedlings, LP is the land wheel perimeter, NUC is the number of used conicals, Z_1 is the number of teeth on the gear chain on the land wheel axis and Z_2 is the number of teeth on the gear chain on the horizontal axis of the distributors.

$$DC = \frac{D_2}{D_1} \times \frac{LP}{NUC} \quad (2)$$

where, D_1 is the diameter of gear chain on land wheel axis, and D_2 is the diameter of gear chain on horizontal axis of the distributors.

Land wheel perimeter is 105 cm with the approximate radius of 17 cm. The ratio of the numbers of gears and the diameter of wheels on the land wheel axis and the horizontal axis of distributors is considered 1. This ratio was chosen based on the distance of seedlings on a row which is equal to 35 cm and the number of active conical in this transplanter which is 3. On the other side of the horizontal axis of distributors, there is another gear chain which is responsible for spinning of the gear chain that moves kicker arm. The ratio of the numbers of teeth in gear chains is related to the aggregate of conical so that with every vertical spin of the distributors, the gear chain connected to the kicker arm should spin as many times as the number of all the distributors. In case of this transplanter which has 3 active conicals, for every spin of the vertical axis, this kicker arm should spin 3 times. The ratio can be obtained through formula (3) [2].

$$\frac{Z_3}{Z_4} = \frac{E_3}{D_4} = \frac{1}{NAC} \quad (3)$$

where, NAC is the number of active conical, Z_3 is the number of gear chain teeth on the horizontal axis of the distributors, Z_4 is the number teeth on kicker arm, D_3 is gear chain diameter of horizontal axis of distributors and D_4 is kicker arm chain gear diameter.

Chassis is composed of wheels, user chair and other joints needed for the machine to be towed. Its purpose is to carry the weight, to maintain the integrity and to connect different parts. Figure 3 shows the overall view of the developed transplanter.

This chassis is 100*150 cm and is 50 cm high above the ground. The distributors are 100 cm above the ground and the distance between the distributor axis and the chair is 80 cm. The machine is 200 kg weights.

Fig. 3 The developed transplanter (1) Three-point joint, (2) Chair, (3) Distributor, (4) Fall tube, (5) Chassis, (6) Furrower, (7) Land wheel

Before the distributors reach the top of the fall tube, the worker picks up a seedling from the tray and applies it vertically in the conical. With the conical reaching to the top of the fall tube, the cam opens the nozzle of the distributor and the seedling enters the falling tube and from there to the furrow made by the furrower. When the seedling is correctly applied in the furrow, a lever guides the seedling into the soil so that it has the proper angle. Leaning surfaces of the furrower cover the seedling with soil and stabilized it. The conical, after passing the fall tube, return to their former position with the help of the spring beside their nozzles, and the nozzles close so that they can repeat the procedure.

In order to evaluate performance of the transplanter, accuracy factors, such as physical damage to seedlings, seedling deployment angle from the vertical line and the distance between cultivated seedlings on the row was investigated. Before the tests began, the soil had been plowed at a depth of 25 cm, and then the ground was leveled.

Due to farm facilities a 110 hp MF399 tractor was used to provide tensile strength. A shaft encoder attached to the wheel axle of transplanter was used to measure the actual forward speed of the machine. Fixing forward speed in quantities of 1, 2 and 3 km h⁻¹ was done by selecting fixed gear in the gearbox of tractor and changing engine speed of the motor, by manual lever.

Due to the design of the transplanter with one cultivation mechanism, the seedlings were planted in one row. Tomato seedlings were cultivated with 35 cm spacing. The seedlings were in four leaves stage at the cultivation time.

The physical damage of seedlings was measured arbitrary. Damage to each leaf: 10%; to stem: 20% (in case of removing stem with leaves from the seedling, this

percentage is calculated for the leaves and its amount increases with each new leaf); to root: 30% (percent listed is for full damage and if they are partially damaged, this amount is reduced). These percentages are measured at the end of transplanting by objective review for each of the planted seedling [2].

Tests were done using a factorial experiment based on complete randomized block design in three replications. The test treatments consisted of three levels of forward speed, including the speed of 1, 2 and 3 km h⁻¹ and cultivation depth in two levels of 5 and 10 cm. The velocity variable is indicated with V (V_1 , V_2 , V_3 are 1, 2 and 3 km h⁻¹, respectively) and the cultivation depth variable is indicated with d (d_1 , d_2 are 5 and 10 cm, respectively). The treatments consist of six combinations that are completely randomized into experimental units (plots) inside the block. The length of each plot was 10 m and plots were 3 m apart. Statistical analysis of the experimental data and data average comparison was done by Duncan's multiple test at 5% level by SPSS22 software. The theoretical capacity of the device was calculated according to the Eq. (4) [9].

$$C_t = \frac{n v D}{10} \quad (4)$$

where, C_t is the machine theoretical capacity (hectares per hour), n is the number of cultivation rows, v is the forward speed of the device (km h⁻¹), and D is the distance between two rows of cultivation (m).

3 Results and discussion

3.1 The effect of forward speed and cultivation depth on the distance between seedlings on the rows

According to Table 1 and Fig. 4, the average planting distance at forward speeds of 1, 2 and 3 km h⁻¹ was 34.82, 35.4 and 35.10 cm, respectively, and the closest planting distance with less standard deviation was at the speed of 2 km h⁻¹. Investigation of different distances at different cultivation depths showed that the average depth of 5 cm (35.02 cm) has less standard deviation (35 cm) than the depth of 10 cm has. The cross-investigation of the table also shows that the most suitable cultivation distance with the least standard deviation was at the depth of 5 cm and the speed of 2 km h⁻¹. On the other hand, the results of Table 2 shows that the error of 0.05 in the forward speed and cultivation depth factors, as well as their interaction and the variable of the block, have no significant effect on planting distance. Therefore, considering the fact that the average distance of planting in all the speeds and cultivation do not have a significant difference, according to the

Table 1 Descriptive indicators of planting distance at different forward speeds and depths

Depth	Speed							
	1		2		3		Total	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Depth1	34.97	0.81	35.02	0.50	35.07	0.98	35.02	0.78
Depth2	34.67	0.80	35.07	0.78	35.13	1.17	34.96	0.95
Depth2	34.82	0.81	35.04	0.65	35.10	1.07

Fig. 4 Average planting distance affected by depth and forward speed

lowest deviation from the standard distance, the speed of 2 km h⁻¹ and the depth of 5 cm creates a more favorable planting distance. Since the rotating power of the wheels is provided by the land wheel and the axis of the distributors is also circles according to it, the increase or decrease

of forward speed increases and decreases the rotational speed of the axis of the distributors. Since the distributors are fixed in a certain distance, it does not have any effect on the spacing between the seedlings in cultivation row. This implies the optimal planting accuracy with this device and the settings made.

3.2 The effect of forward speed and cultivation depth on physical damage of seedlings

The results of Table 3 and Fig. 5 shows that in the cultivation depth of 5 cm, the average damage was 89.5% and in the depth of 10 cm, 6.67%. In addition, the average damage at the forward speeds of 1, 2 and 3 km h⁻¹ were 3.17%, 5.83% and 9.83 km h⁻¹, respectively. As the speed of the device increases, the physical damage to the stems, leaves and roots increases.

Table 2 ANOVA results of planting distance at different forward speeds and depths

Source	Sum of squares	Degrees of freedom	Average sum of squares	F	p value	Eta square
Block	1.003	2	0.501	0.688	0.514 ^{ns}	0.008
Speed	2.686	2	1.343	1.790	0.170 ^{ns}	0.020
Cultivation depth	0.168	1	0.168	0.224	0.637 ^{ns}	0.001
Interaction between forward speed and cultivation depth	1.286	2	0.643	0.857	0.426 ^{ns}	0.010
Error	129.072	172	0.750			
Cv%	–	–	–		2.48	

^{ns}Non significant difference

*Significant at the 5% level, **significant at the 1% level

Table 3 Descriptive indicators of physical damage of seedlings at different forward speeds and depths

Depth	Speed							
	1		2		3		Total	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Depth1	33.3	5.47	35.02	5.33	6.81	9.00	10.29	8.06
Depth2	3.00	5.35	35.07	6.33	7.65	10.67	11.12	8.87
Depth2	3.17	5.371	35.04	5.83	7.20	9.83	10.66

Fig. 5 Average of physical damage of seedlings at different forward speeds and cultivation depths

Because with the forward speed increasing, the speed of different mechanisms increases too. This is due to an increase in the speed of distributor's kicker arm mechanism. This increase in speed will cause the nozzle to begin the closing action sooner, resulting in damage to the transplant. On the other hand, the kicker arm will also hit the transplant, which will cause more damage. From the data in Table 4, it is also observed that the effect of forward speed on physical damage to the seedling is significant ($P < 0.0001$); on the contrary, the depth of cultivation did

not have a significant effect. According to the results of Duncan test, it was observed that the forward speeds of 1 and 2 km h^{-1} are in the class of B and the forward speed of 3 km h^{-1} is in the class of A; therefore, there is no statistically significant difference between the forward speeds of 1 and 2 km h^{-1} . Given that the optimum speed of 2 km h^{-1} had the least deviation of the planting distance, and also due to the insignificant effect of cultivation depth and the interaction between depth and speed, it was observed that, in general, at the depth of 5 cm, the average physical damage to the seedlings is in the lowest level.

And due to the lack of differences at the speeds of 1 and 2 km h^{-1} , in this section, speeds of 1 and 2 km h^{-1} and the depth of 5 cm are introduced as the appropriate speed and depth with minimized physical damage to the seedlings.

3.3 The effect of forward speed and cultivation depth on establishment angle of seedlings

The results of Table 5 and Fig. 6 showed that the average deployment angle at the speeds of 1, 2 and 3 km h^{-1} was 1.83, 2.75 and 5.58°, respectively. As the speed increases, the seedling deployment angle increases. Since the

Table 4 ANOVA results of seedlings physical damage

Source	Sum of squares	Degrees of freedom	Average sum of squares	F	p-value	Eta square
Block	34.444	2	17.222	0.261	0.771 ^{ns}	0.003
Speed	1351.111	2	675.556	10.226	0.000**	0.106
Cultivation depth	27.222	1	27.222	0.412	0.522 ^{ns}	0.002
Interaction between forward speed and cultivation depth	31.111	2	15.556	0.236	0.790 ^{ns}	0.003
Error	11362.222	172	66.059			
Cv%	–	–	–		121.66	

^{ns}Non significant difference

*Significant at the 5% level, **significant at the 1% level

Table 5 Descriptive indicators of transplanting angle at different forward speeds and cultivation depths

Source	Sum of squares	Degrees of freedom	Average sum of squares	F	p-value	Eta square
Block	1.944	2	0.972	0.048	0.953 ^{ns}	0.001
Speed	458.611	2	229.306	11.416	0.000**	0.117
Cultivation depth	108.889	1	108.889	5.421	0.021*	0.031
Interaction between forward speed and cultivation depth	58.611	2	29.306	1.459	0.235 ^{ns}	0.017
Error	3454.722	172	20.086			
Cv%	–	–	–		141	

^{ns}non significant difference

*Significant at the 5% level, **significant at the 1% level

Fig. 6 Average of transplanting angle affected by forward speeds and cultivation depth

speed increases, speed of the various mechanisms of the machine increases, that will cause shaking in the body, especially in the furrower; on the other hand, with the speed increasing, the intensity of the soil back to the furrow created by the groove is increases, which could lead to a further change in the angle of deployment of the seedlings from the vertical position. On the other hand, as the cultivation depth increases, the angle of deployment of the plant increases, so that at the depth of 5 cm, the average deployment angle was 2.61° and at 10 cm depths, it was and 17.4 . In fact, with the increase in cultivation depth due to the increase in the height of the fall and also the increase in soil movement, the deployment angle from the vertical line increases. Table 6 shows that at the 5% probability level, the speed and depth factors have a significant effect on the deployment angle, but their interactions and the block factor have no significant effect on it. The minimum angle of deployment is at 5 cm depths, and in Duncan's multiple test there is no statistically significant difference between the two speeds of 1 and 2 km h^{-1} . Therefore, according to the previous results, the speed of 2 km h^{-1} and a depth of 5 cm will provide an optimal position in terms of the deployment angle.

3.4 Theoretical capacity of the machine

Considering that speeds of 1 and 2 km h^{-1} have similar performances statistically, at the depth of 5 cm, a better performance was observed, and with the least standard

deviation of the planting distance, the speed of 1 km h^{-1} and a depth of 5 cm were selected as the preferred options. With the forward speed of 2 km h^{-1} , and considering 40 cm distances between the cultivation rows, we can calculate the theoretical capacity of the device by Eq. 5:

$$C_t = \frac{2 \times 40}{10} = 0.08 \text{ hah}^{-1} \quad (5)$$

Therefore, the plant's capacity, in one cultivation row, is 0.08 hah^{-1} , although, given the actual conditions and the time required to service, repair, turn over, etc. the real capacity will be less. To increase the capacity of the machine, increase the number of rows of cultivars and it is suggested to be used for cultivating the four-row machine.

4 Conclusion

According to the results, it was observed that the interaction between the forward speed and cultivation depth on the variables studied was not affected and the effect of the forward speed was significant only on the deployment angle and damage to seedlings. The variables of forward speed and cultivation depth on the distance between the seedlings do not have any significant effect. The results indicated that by increasing the speed and cultivation depth, deviations from the standard spacing, physical damage and deployment angle increase, so that at the depth of 10 cm and the speed of 3 km h^{-1} , the highest values were observed. On the other hand, at the cultivation depth of 5 cm, in comparison with 10 cm depths, physical damage and deployment angle were more logical. Given that at the speed of 2 km h^{-1} , performance of the machine was better than the speed of 1 km h^{-1} , but statistically, the two speeds have the same performance. But on the other hand, reducing the forward Speed will reduce the capacity of the device, which is not logical. Therefore, due to the similar statistical effect and higher theoretical capacity of the machine at the speed of 2 km h^{-1} , the speed of 2 km h^{-1} and the depth of 5 cm were expressed as the optimum levels used in the research. Accordingly, with the

Table 6 ANOVA results of transplanting angle

Depth	Speed							
	1		2		3		Total	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Depth1	2.67	1.50	3.88	2.33	4.81	4.00	3.98	2.61
Depth2	3.13	2.17	4.45	3.17	6.65	7.17	5.37	4.17
Depth2	2.91	1.83	4.16	2.75	5.97	5.58	4.78	3.39

forward speed of 2 km h⁻¹ and the distance of 40 cm, the theoretical capacity of 0.88 hah⁻¹ can be achieved.

Compliance with ethical standards

Conflict of interests The authors declare that they have no conflict of interest to the publication of this article. There are no copyrights relevant to this work. There are no relationships or activities to disclose that could be perceived to have influence the submitted work.

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